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Methods of Reinforcing Concrete

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METHODS
OF
REINFORCING CONCRETE

...BY...

Robert Bennett Roulston

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN CIVIL ENGINEERING

COLLEGE OF ENGINEERING
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OF Bachelor of Science in Civil Engineering.

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HEAD OF DEPARTMENT OF Civil Engineering.

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HISTORICAL DEVELOPMENT.

The earliest and the most extended applications of concrete reinforced with metal have been made in France, and it is by French engineers that the most scientific study has been given to this new type of construction. The first reinforced concrete structure to attract notice was exhibited at the Paris Exposition in 1855. This was a small row-boat in which the planks of the shell were made of concrete reinforced by a small wire net. It was about this

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time that Coignet built a number of iron-concrete dams.

About the year 1861, James Monier, a gardener in Paris, found by embedding fine iron wires in the walls of cement flower pots that they were considerably strengthened. Monier was far from being a trained engineer, and was not the first to use reinforced concrete; yet he has become famous, because his inventions and methods have formed a nucleus for the great number of systems which have been developed. In 1867 he obtained from the French government the first patent on reinforced concrete, and subse-

quently built many engineering structures. In a comparatively short time he erected nearly 1000 water tanks, some of them 10 feet in diameter and 11 feet high.

In 1867 at the Paris Exposition, Coignet showed conduit pipes and ceilings reinforced by two systems of endless iron wires at right angles to each other.

Only comparatively slight interest was shown in reinforced concrete construction until 1872 when it was established by Considere, Bourniceau, Mesanger, and others that concrete adheres well to iron, prevents its rusting, and take

part in the elastic expansion and contraction of the metal. With the announcement of these conclusions reinforced concrete grew rapidly in favor, and there are at present something like two hundred methods. Many of these are, however, mere repetitions of each other, differing only in some minor and unimportant details. A description of the most important methods will be made under three general heads:

I. Steel lathing.

II. Bar Reinforcement.

III. Miscellaneous.

I. STEEL NETTING.

Under this heading is included all those methods now in use in which the reinforcement is accomplished by embedding a steel or iron net in the body of the concrete.

Monier System.

In the Monier system a metal net is formed by running two series of iron or steel wires at right angles to each other and joining them at their intersections. This net is embedded in the body of the concrete, and is

signed to take the tensile stress that may come upon the structure. This was the earliest method of reinforcing concrete, and has been used extensively in Europe, particularly in the construction of arch bridges. The original Monier arch had only one wire net on the intrados, but at present in large spans two are used, as one alone is not sufficient to carry the stress. One of the largest Monier bridges ever built is that at Bremen, Germany. It has a span of 132 feet, a rise of 14 3/4 feet, and a thickness at the crown of only 9 7/8 inches. The whole structure was completed in

weeks, the main span taking just thirty-six hours. In Switzerland a number of Monier arches have been built, the one at Wildegg and the one at Aaran, both having spans of 128 feet. The dome over the mausoleum of Frederick III. at Potsdam was constructed according to the Monier system, which style of steel-concrete construction the German government has always given its highest endorsement.

For additional information on this system see.

1. Engineering News, first volume for 1896, page 238, an article giving a description and the results of a series of tests

made in Austria on brick, concrete, steel, and Monier arches having spans from 4.34 feet to 75. feet. This is an exceedingly valuable series of experiments.

2. Engineering News, first volume 1893, page 148, a general description of a number of Monier arches that have been built in Germany. Illustrations are shown of arches of spans varying from 63 ft. to 114 ft., and of a 9 ft. sewer in use in Hamburg.

3. Engineering News, December 11, 1902, a valuble article giving an illustrated description of the Monier concrete-steel cement storage tanks of the Illinois Steel Company. These tanks are 55 ft

high, and have an inside diameter of 25 feet. They rest upon a number of concrete piers reinforced with railroad rails. The height over all is about 70 ft.

4. London Engineering, September 12, 1902, page 336, a short description of the Monier, Koenen, Hennebique and Wayss systems is given, showing the principal characteristics of each. This is a very general description and not very important, being a small part of a very valuable article on the chemical and metallurgical industries at the Dusseldorf Exhibition.

5. Journal of the Western Society of Engineers, June 1900,

an extensive and highly valuable paper on Monier construction by E. Lee Heidenreich read before the society. The article contains an unusually large number of illustrations and is followed by interesting discussions by H. W. Parkhurst, Ralph Modjeski, Prof. J. B. Johnson, and others.

Weunsch System.

The Weunsch system of reinforcement, proposed by Robert Weunsch of Buda Pest, is merely a modification of the Monier method, the wire netting of the latter being replaced by stiff angle or T. sections

system has been used mostly in the construction of floors and arches. In the construction of an arched floor in a large brewery in Buda Pest, the intrados of the girders consisted of two 2.16" x 2.16" x 0.28" angles bent to conform with the curve of the arch. The extrados was flat and was made up of angles of the same size as the intrados. The girder was then completed by encasing this framework in concrete.

Bridges have also been built using this system, an example being the highway bridge at Szechanszek, Hungary. This is an iron-concrete structure having a span of 55⅓ ft. and a rise of 3¾ ft. Another Wünsch

bridge is located at Belovar, Hungary, and has a span of 41⅓ ft. and a rise of 3 ft.

The following articles give additional information on this subject:-

1. Cement and Engineering News, a series of illustrated articles on armored concrete construction by E. Lee. Heidenreich, beginning March 1903 to date. An abbreviated history of reinforced concrete is given and is followed by an extended description of structures that have been built under the various systems. This is a very valuable work.

2. Engineering News, volume I, 1894, page 305, an illustrated

article describing the Wemmel and Melan systems of floor construction. A transverse section of a brewery at Buda Pest shows the Wemmel system of floor construction in detail.

3. Engineering News, 1893, volume II, page 391, a description of a Wemmel arch bridge at Newhaven, Hungary. This bridge has six spans of 55.8 ft. each, a rise of 44.5 inches, and a thickness at the crown of 9.5 inches. The cost of this bridge was $13,700; and the time of erection was four months.

Cottancin System.

This system, which was first used in France about the year 1889, consists of a network of steel or iron wires woven in place. These reinforcing wires are woven back and forth between through wires, the closest weaving being at the points of greatest stress. In case the weaving at these points of maximum loading would make the mesh too fine and thus prevent good adhesion with the concrete, larger wires are used.

This system is employed mostly in the construction of floors

and ceilings, which are reinforced by what M. Cottancin terms. "Spine Reinforcement." In this case he employs beams of concrete formed about a metallic skeleton and placed on edge, to obtain the maximum resistance to bending. The wires of these beams are interwoven and the network of the floor is joined to them.

Additional information on this system may be obtained from;

1. Engineering Magazine, January 1902, an illustrated article by Jacques Boyer on the different methods of reinforcing concrete.

2. London Architect

December 19, 1902, a valuable article describing the Cottan-in type of construction.

3. Cement and Engineering News, a series of articles by E. Lee Heidenreich, March 1903 to date on armoured concrete construction.

II. Bar Reinforcement.

This method consists of embedding bars of considerable size in the concrete instead of wires as in the preceding systems. In some forms of this system the bars are plain and in others they are of special design intended to increase the adhesion of the concrete to the steel.

Plain Bars.

A method of reinforcement which has been used a great deal in the past is embedding plain round or square bars in

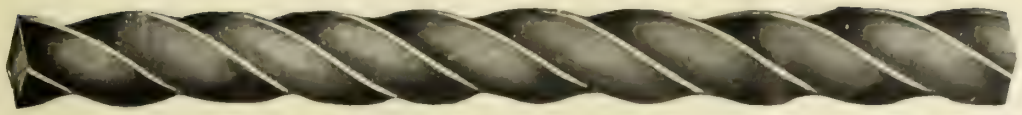
the concrete. Fred G. Edwards, of Leighton-road, North Wales, was one of the first to use the plain bar reinforcement successfully. The results of tests made by him as early as 1891 upon a number of beams show the value of this method. He found that while a beam of plain concrete failed under a load of 431 pounds, one of the same size reinforced with round rods was able to sustain an average load of 2,500 pounds. The adhesion of the concrete to the metal in all these experiments remained good, no rods being pulled out, though in some cases the beams failed by horizontal

shear along the line of the rods.

Ransome System.

The Ransome system has the distinction of being the first American method of reinforcing concrete which was at all successful. It was invented by Mr. Ernest L. Ransome of San Francisco, and has been extensively used, at least in this country. It is distinguished from the preceding systems by an attempt to increase the bond between the steel and the concrete. The reinforcement in the Ransome system is a square bar of steel twisted cold (see Fig. 1.); and to

RANSOME SYSTEM



NOVEMBER 1903

Fig. 1.

understand the mechanical bond of the concrete to the twisted bar it is only necessary to call to mind the holding power of a screw in wood. It is a fact that a bar of steel twisted cold is superior to a plain one as regards strength per pound of metal. This is explained on the ground that the twisting of the bar draws the fiber of the metal closer together and compacts it. The following table gives the comparative strength in pounds per square inch, of untwisted and twisted

bars made from the same lot of mild steel. These tests were

SIZE AND CONDITION	ELASTIC LIMIT	ULTIMATE STRENGTH
¼ inch, plain	46170	57800
¼ " twisted	62350	86700
¾ " plain	34840	59200
¾ " twisted	56720	85240
⅞ " plain	39700	62100
⅞ " twisted	56150	84730

made at Columbia University, and the results given are the average of four or more tests.

In brief the inventor claims for this system the following advantages: (1) a higher elastic limit and a greater ultimate stength; (2) a mechanical bond with the same net section from end to end; (3) no waste of steel in lugs or projections; (5) the merit of the method is proven by the large amount of

work executed in this country.

As to the amount of steel to be used in the cross-section, Mr. Leonard C. Wasson, who has built a great many structures using the Ransome bar, advises the following: for a 1:3:6 concrete and using the stress in the steel equal to 16,000 pounds per square inch, the area of steel to the area of concrete should be about as 1 to 32. This is about 3.1 per cent and in the writer's opinion seems high and does not agree with the practice of most engineers.

Among the many examples of structures built by the Ransome method may be noted: the Nassau County Court House, Mineola, Long Island; a concrete chimney, height

108 feet, internal diameter 8 feet, at Jersey City, N.J.; a 33 ft. span bridge at Upper Salford, Pa.

The following references give additional information on this system:

1. Cement und Eisenbau, an article on armored concrete constructions by E. Lee Heidenreich beginning March 1903.

2. Beton und Eisen, No. III, 1903, a tabulated report of a series of tests made upon the bond between concrete and steel by C. W. Spofford at the Massachusetts Institute of Technology.

3. Engineering Record, December 20, 1902, an article describing a

series of tests on Ransome concrete steel floor construction.

4. Engineering Record, January 31, 1903, an article giving a comparison between the Hennebique and the Ransome systems.

Johnson System.

The distinguishing feature of the Johnson system is the use of a bar like that shown in Fig. 2. The object of corrugations

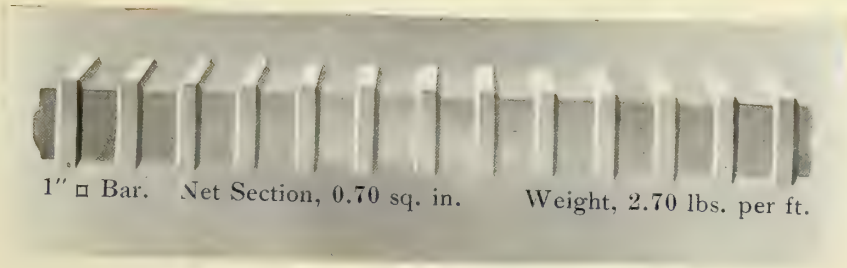


Fig 2. Johnson bar.

is to increase the bond between the steel and the concrete. The invent-

or, Mr. A. L. Johnson of St Louis, Mo, states that experiments with plain bars showed how very easy it was to break the adhesion between the concrete and the metal, and that it was therefore not safe to use a plain bar, or any form of bar that depended upon adhesion alone for its efficiency. He further says that the bar should be provided with some form of ribbing device, the sides of these ribs being nearly at right angles to the axis of the bar, varying therefrom by an angle not exceeding the angle of friction between the materials used. Upon these principles Mr. Johnson has designed his corrugated bar shown

in Fig. 2. This bar is rolled bar from special material, and more work is put upon it than is given ordinary structural steel. These bars are made in sizes varying from ½ inch to 1½ inches in thickness.

The following articles give interesting matter concerning this method of reinforcement:

1. Engineering News, July 13, 1905, a paper by Prof. W. K. Hatt of Purdue University, giving the results of tests made at Purdue on concrete-steel beams and the methods of making these tests. The beams were made of broken stone concrete reinforced with 1 per cent and 2 per cent of wrought iron located at differ-

cut positions in the cross-section. A large number of cuts and diagrams accompany this valuable article.

2. Beton und Eisen, No III, 1903, an account of tests made at the Massachusetts Institute of Technology upon the bond between concrete and steel.

3. Railroad Gazette, March 13, 1903, an article by Mr A. L. Johnson on his type of steel-concrete construction.

4. Transactions of the American Society of Civil Engineers, volume 46, 1901, a contribution to the discussion on "Steel Concrete Construction" by Mr. A. L. Johnson.

Thacher System.

In this system steel bars of special design, spaced at proper distances and spliced at convenient intervals, are imbedded in the concrete. The different lines of bars are not connected with each other. The bars were formerly provided with projections of rivet-heads or lugs at short intervals, to reinforce in a mechanical way the adhesion of the concrete to the steel; but at present these lugs are not used, a special bar known as the Thacher bar (see Fig. 3) being employed instead. These bars are laid with their widest dimension horizontal. The

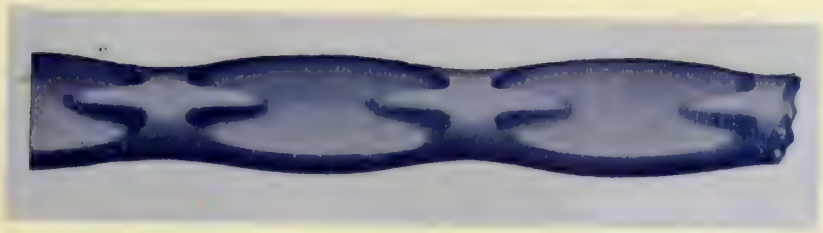


Fig 3. Thacher bar

inventor recommends that the distance from the center of the bars to the outside of the concrete should not be less than one and one-half times the diameter of the bar. The sizes of the bars vary from ¼ inch to 2 inches in diameter.

The inventor gives the following advantages of these bars: (1) a more reliable connection between the steel and the concrete is obtained than in any other system depending upon adhesion alone; (2) these bars can be shipped with ease and

can be bent cold to any desired curve.

For additional information on this system see;

1. Beton und Eisen, No II, 1903, a report of tests made at the Massachusetts Institute of Technology, by C. M. Spofford, upon the bond between concrete and steel. The rods used were of the Johnson, Ransome and Thacher types.

2. Engineering News, September 21, 1887, Edwin Thacher gives an account of various systems as applied to a bridge.

3 Engineering News, February 12, 1903, an article by Edwin Thacher giving the results of tests made by Prof. W. K.

Hatt of Purdue upon steel-concrete beams. The concrete used was of 1:2: broken brick, and 1:2:4 and 1:3:6 broken stone; and the variation in area of metal used was between 0.31 per cent and 3.9 per cent.

Kahn System.

The Kahn system first suggested itself to its inventor after a series of extensive experiments made by him upon concrete beams reinforced with steel bars of various shapes and sections. He found that without a single exception these beams under a uniform load failed by vertical or longitudinal shear.

These facts led him to seek some method which would reinforce the beam against vertical as well as longitudinal shear.

This problem of vertical reinforcement had been partially solved by European engineers by placing iron or steel stirrups in the beam at varying distances apart, so that the stirrups would cross the lines of rupture at an angle and hold the concrete together. Mr. Kahn commends this method, but suggests that the stirrups could be made much more effective if they were inclined to the vertical, preferably with an upward curvature which would approximate the line of principal tensile stress. He also

advises distributing the metal in the beam in proportion to the strains existing at different points. Again he advocates connecting the shear members rigidly to the horizontal reinforcement.

The Kahn bar, shown in Fig. 4, was designed by its inventor to meet all the above requirements. A cross-section of

The Kahn Trussed Bar.

Fig 4.

the bar is shown in Fig. 5. The web being sheared upwards into an inclined position on both

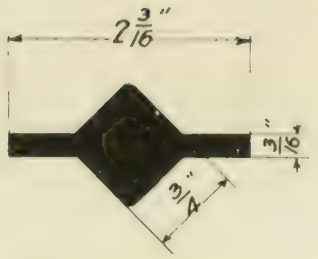


Fig. 5. Cross-Section
Kahn Bar

sides of the main body, thereby forming substantially the tension members of a Pratt truss. When a bar of this shape is embedded in a beam of concrete, the latter takes compression, while the steel carries the tensile stresses.

One advantage of the Kahn system over several others, is the absolute impossibility of the steel's slipping in the concrete. Another is that the beam may be made comparatively narrow at the bottom, since it need be only suff-

iciently wide to encase the steel to prevent its rusting. It should widen upwards however, so as to lessen the unit compression stress in the concrete. Mr. Kahn claims that a beam reinforced with this style bar can fail in but two ways: either by the crushing of the concrete, or by the steel's pulling in two.

For additional information on the Kahn system see:

1. Railroad Gazette, October 16, 1903, an article by Julius Kahn describing this system and defending the trussed bar. The article is illustrated both with photographs of tests on beams, and with cuts showing the principal characteristics of the Kahn bar.

2. Catalogue by the Turner Construction Company, Detroit, Mich., gives a full description of the Kahn bar with illustrations, and a number of formulas for steel-concrete beams.

3. Engineering News, January 21, 1904, an article by Julius Kahn on some of the recent failures of reinforced concrete. The author gives as the principal causes of failure, the lack of proper scientific reinforcement, the use of poor materials, and careless mixing.

III. MISCELLANEOUS.

The methods included under this head might be roughly described as a more or less rigid framework covered with concrete.

MELAN System.

The Melan system consists of embedding steel I beams in the concrete. This is one of the oldest methods of reinforcement. Because of its ability to sustain extra heavy loads it has been used extensively in the construction of bridge and factory floors. The following is an account of the erection of a Melan arch floor beam for a large factory at Teschen, Austria. I

beams were first laid in place, and then the concrete was filled in between them, extending below the flange of the lower curved I and being flush with the upper flange of the arch. The connections between the floor-beams and the stringers were made rigid by means of wedges, no rivets or bolts being used.

The same general method is followed in the construction of a Melan bridge floor and a few of the arguments advanced in favor of this style are: (1) it has a damp-proof surface and requires but little expense for maintenance; (2) tests upon Melan and corrugated steel floors under the same conditions as regards

size and manner of loading have shown the former to be much the stronger; (3) the Melan floor needs no riveting and is consequently cheaper than the steel one.

Additional information on the Melan system may be obtained from the following articles:

1. Transactions of the American Society of Civil Engineers, April 1894, gives an account of the development of reinforced concrete and explains the Melan system. This article is by Fr. von Emperger and is an exceedingly valuable one.

2. Engineering News, April 7, 1892, page 220, gives a description of a Melan concrete and steel arch bridge at Topeka, Kan.

This bridge has five spans, one 125 ft., two 110 ft., and two 91½ ft., a roadway 26 ft. wide and two walks each 7 ft. in width.

5. Engineering Record February 13, 1904, gives an illustrated description of the Fourth Street Iowan bridge at Waterloo, Iowa. The total length of the bridge is 586 feet, and is made up of 7 spans.

6. Railroad Gazette Jan. 13, 1899, gives a description of the Iowan system and also states that iron which submitted to certain tests for many years were found perfectly free from rust

Hennebique System.

The Hennebique system of reinforcement is today without doubt the most widely used of any in the world and its great success is due to the careful and scientific study given it by its inventor. M. François Hennebique, was the first engineer to grasp the importance of taking care of the shearing stresses in a beam and his designs have made his name famous in Europe.

The beam which he designed is constructed by embedding in the beam shoes, pairs of iron rods, one bent always straight at the other [illegible]

wards near the supports, the two being united by bent stirrups or stirrups. The concrete and the steel rods may be regarded as forming queen post trusses, the place of the wooden chords being taken by the concrete and that of the verticals by the rods and stirrups. The stirrups are spaced closest at points of maximum shear, which in the case of a beam simply supported at the ends is at the ends.

In the construction of an arched floor for the Petit Palais des Arts at the Paris Exposition, a series of beams placed at right angles to the axis of the arch and spaced one metre (3.28 ft.) apart were used

Each of these beams consisted of two 17 m.m. (6.7 in.) iron rods embedded in concrete. One of these rods was placed just below the surface of the floor and extended well into the supporting walls. The other was placed just inside the intrados of the arch and was also built into the side walls. The beam was completed by uniting these rods by a series of iron lattices 30 m.m. by 2 m.m. and then encasing the whole in concrete.

For additional information on the Hennebique system see the following articles:

1. Cement and Engineering News, a series of articles beginning March 1903, by E. Lee

Heidenreich on armoured concrete construction. The various systems are described in detail and a large number of illustrations are given of structures built according to the Hennebique system.

2. Engineering Record, August 22, 1903, gives an account of a Hennebique water tower near Boston.

3. Journal Association of Engineering Societies, September 1902, a very valuable article by Leopold Mensch on the Hennebique system.

4. "Reinforced Concrete," a book by Leopold Mensch published by Cement and Engineering News Company, Chicago, Ill., gives an illustrated account of reinforced

concrete paying particular attention to the Hennebique system.

5. Engineering Record, June 31, 1903, gives an account of the Hennebique system and compares it with the Ransom method

6. Engineering Magazine, January 1902, an illustrated article by Jacques Boyer on the Bonna, Hennebique, Ransome, Cottancin, Turkan and Monier systems of reinforced concrete

Bonna System.

In the Bonna system the reinforcement is a steel or iron framework bolted or riveted at the connections, encased or embedded in the concrete. The

of the inventor was not only to produce a monolithic structure of concrete, but also to provide it with a metallic skeleton. In fact an edifice constructed according to this system is distinguished from that of an ordinary building only by the lightness of the framework, the small number of bolts, and the absence of braces and reinforcing plates. The few bolts and rivets that are used are merely for the purpose of keeping the structure rigid while the concrete is setting.

Forms of rolled sections other than round rods are preferred, because of their greater rigidity and of the ease of con-

coin.

The cross-sections of the members of the metal framework are in the form of a cross. These forms have a greater moment of inertia than the round rods for the same sectional area, and connections can be more easily made with them than with round or square bars. They also permit of the use of joint-coin plates, and thus the whole structure may be assembled and united into a continuous whole. This system has found much favor in France in the construction of floors and sewers.

Additional information on the Bonna system may be obtained from the following articles

1. Engineering Magazine, January 1902, an article by Jacques Boyer which gives an illustrated description of structures built by this system.

CONCLUSION.

As with every new type of construction reinforced concrete has met with innumerable obstacles which so far it has entirely overcome. The question has been asked: does the steel rust? In answer to this the writer can do no better than give the observations of two leading engineers on this subject. First, some years ago in Minneapolis

to remove all doubt as to rusting urged the city authorities of Grenoble, France to make an examination of a steel-concrete water main that had withstood a head of 75 feet for over 15 years. When this main was taken up not the slightest trace of oxidation could be found and the adhesion was so good that the concrete could be separated from the steel only by heavy blows of a sledge. Again, Jno. C. L. Ransome of San Francisco, states that a reinforced concrete walk laid in 1883 around the Bowling Green Park, New York City, which was just recently torn up by the Rapid Transit Company, showed the

perfect condition.

Another question and one upon which engineers have varying opinions is the amount of reinforcement to be used. This is largely to be determined by the circumstances attending the case, the ideal reinforcement being that which develops the entire compressive strength of the concrete. Prof. W. K. Hatt of Purdue gives as a minimum to be used 0.3 per cent and for a maximum 2.0 per cent.

During the earlier development of steel-concrete construction it was supposed that the coefficient of expansion of the concrete and the steel was identical, and the absence of temperature cracks

was explained on that basis. But later experiments by Prof. W. K. Pence of Purdue University, (reported in the Journal of the Western Society of Engineers), and others have shown the coefficient of expansion of concrete to be 0.00000 5 and that of steel 0.0000065; or 15 per cent less for concrete than for steel. M. Considere has also shown that where ordinary concrete under a tensile stress will sustain an elongation of but 1 in 10,000. without rupture; if properly reinforced, it will stand more than 1 in 1000.

Among the many features of reinforced concrete which render it particularly suitable for engineering structures may be briefly

noted the following:

1. It may be stressed as high in tension as in compression.

2. When properly reinforced it is not ruptured by changes of temperature within limits between which plain concrete will crack.

3. It improves with age and is more permanent than stone.

4. It may be moulded to any form and requires the employment of very little skilled labor.

5. It is fire-proof, and the steel embedded in the concrete is rust-proof.

In closing the author feels that some mention is due

those men who have succeeded in bringing before the world a new type of construction that bids fair to change the steel or iron age to an age of reinforced concrete.

At the present time we have only seen the beginning and yet a careful study of the situations shown as the great possibilities of this new construction

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